②

AIR FORCE

AD-A232 574

H U M A N

REPETITION OF SEMANTIC COMPARISONS: TEMPORARY AND PERSISTENT PRIMING EFFECTS

Dan J. Woltz

MANPOWER AND PERSONNEL DIVISION
Brooks Air Force Base, Texas 78235-5601

R E S O U R C E S

DTIC
ELECTE
MAR 1
S
G

LABORATORY

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5601

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Public Affairs Office has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

WILLIAM E. ALLEY, Technical Director
Manpower and Personnel Division

MICHAEL W. BIRDLEBOUGH, Colonel, USAF
Chief, Manpower and Personnel Division

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE January 1991	3. REPORT TYPE AND DATES COVERED Interim – July 1988 to June 1990	

4. TITLE AND SUBTITLE Repetition of Semantic Comparisons: Temporary and Persistent Priming Effects	5. FUNDING NUMBERS PE - 61102F PR - 2313 TA - T1 WU - 33
6. AUTHOR(S) Dan J. Woltz	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Manpower and Personnel Division Air Force Human Resources Laboratory Brooks Air Force Base, Texas 78235-5601	8. PERFORMING ORGANIZATION REPORT NUMBER AFHRL-TP-90-72

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Two experiments tested the involvement of both abstract semantic memory representations and instance-specific memory for feature encoding in repetition effects for a semantic processing task. Experiment 1 showed that a relatively small amount of facilitation (10%-15%) was attributable to memory for instance-specific features (typography) of repeated trials. Although small, this effect showed no decay over repetition lags investigated, suggesting persistent memory for encoded features or encoding processes. Experiment 2 showed that facilitation for semantically related repetitions was short-lived compared with facilitation for lexically exact repetitions. This suggested that priming of abstract semantic memory may be involved in temporary but not persistent repetition effects. Individual differences analyses supported the conclusion that despite the increased semantic complexity of this repetition priming task over those previously used, abstract semantic memory representations were not involved in persistent repetition effects.

14. SUBJECT TERMS memory instance-specific memory semantic memory representation	15. NUMBER OF PAGES 17
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

REPETITION OF SEMANTIC COMPARISONS:
TEMPORARY AND PERSISTENT PRIMING EFFECTS

Dan J. Woltz

MANPOWER AND PERSONNEL DIVISION
Brooks Air Force Base, Texas   78235-5601

Reviewed and submitted for publication by

Joseph L. Weeks
Chief, Cognitive Skills Assessment Branch

SUMMARY

Two experiments were performed to determine whether repetition effects (improved performance over repeated trials) are primarily attributable to abstract semantic memory or to instance-specific memory. Previous research has been ambiguous, owing to limited involvement of abstract semantic memory. Experiment 1 examined the role of instance memory for physical feature encoding by observing reductions in repetition effects when typographic details were changed (e.g., from "moist damp" to "MOIST DAMP"). Results showed small but persistent reductions, suggesting that instance-specific memory for encoded physical features or encoding processes was involved. However, the small size of the effect did not rule out some additional involvement of abstract memory for stimulus meaning. Experiment 2 attempted to assess effects due to abstract semantic memory by semantically similar repetitions (e.g., "moist damp" vs. "soggy wet"), as well as exact identity repetitions (e.g., "moist damp" vs. "moist damp"). A short-lived (i.e., 7 seconds) repetition effect for abstract repetitions was found. However, repetition effects persisted much longer for identical repetitions than for semantically similar ones. Further analyses of the data from the two experiments found that individual differences in vocabulary scores related almost exclusively with performance increments on semantically related repetitions and that individual differences in performance on two working memory tasks correlated uniformly across all repetitions. The present results may be interpreted as favoring skill acquisition/retention theories that use instance memory rather than some abstract strengthening process.

PREFACE

Repetition of Semantic Comparisons:
Temporary and Persistent Priming Effects

Dan J. Woltz
USAF Human Resources Laboratory, Brooks Air Force Base, Texas

Two experiments tested the involvement of both abstract semantic memory representations and instance-specific memory for feature encoding in repetition effects for a semantic processing task. Experiment 1 showed that a relatively small amount of facilitation (10%-15%) was attributable to memory for instance-specific features (typography) of repeated trials. Although small, this effect showed no decay over repetition lags investigated, suggesting persistent memory for encoded features or encoding processes. Experiment 2 showed that facilitation for semantically related repetitions was short-lived compared with facilitation for lexically exact repetitions. This suggested that priming of abstract semantic memory may be involved in temporary but not persistent repetition effects. Individual differences analyses supported the conclusion that despite the increased semantic complexity of this repetition priming task over those previously used, abstract semantic memory representations were not involved in persistent repetition effects.

People take less time to perform a repeated processing event than the original event, particularly if the two events occur close in time. This seems obvious and has been demonstrated on numerous occasions with different cognitive tasks. A less obvious claim is that this phenomenon may reflect the same underlying memory processes that are responsible for many forms of knowledge and skill acquisition. After all, much of everyday learning occurs on the basis of repeating the same processing event many times, becoming more efficient with each repetition. If this claim is valid, understanding the mechanisms of facilitation from single repetitions of processing events may be of considerable psychological importance.

Early chronometric demonstrations of what is called *repetition priming* or the *repetition effect* reported facilitation up to 100 ms on repeated trials of a two-choice reaction time task (Bertelson, 1961, 1963; Bertelson & Renkin, 1966). Subsequent work demonstrated greater and longer lasting facilitation for repeated processing events in more complex verbal tasks such as old-new recognition for word lists (Hintzman, 1969; Ratcliff, Hockley, & McKoon, 1985; Scarborough, Cortese, & Scarborough, 1977), word naming (Scarborough

et al., 1977), word identification (Feustel, Shiffrin, & Salasoo, 1983; Jacoby, 1983; Jacoby & Dallas, 1981; Jacoby & Hayman, 1987; Salasoo, Shiffrin, & Feustel, 1985), and lexical decision (Dannenbring & Briand, 1982; Forbach, Stanners, & Hochhaus, 1974; Ratcliff et al., 1985; Scarborough et al., 1977).

Despite relative consistency concerning the existence and apparent increased longevity of repetition effects with task complexity, there have been differences in interpretation with respect to underlying memory mechanisms. In general, there have been two classes of interpretation. One attributes repetition effects to increased availability of abstract memory representations that existed prior to the repeated processing event. That is, faster repeated trial performance is attributed to residual activation or lower thresholds of existing lexical or semantic memory codes for stimulus words (Dannenbring & Briand, 1982; Forbach et al., 1974; Johnston, van Santen, & Hale, 1985; Morton 1979; Scarborough et al., 1977). The alternative interpretation attributes repetition effects to some form of instance memory rather than the priming of abstract memory. According to this interpretation, memory for perceptual features or feature encoding operations from prior processing episodes facilitates subsequent encoding of the same stimuli (Jacoby, 1983; Jacoby & Hayman, 1987; Kolers, 1976; Kolers & Roediger, 1984). Although most researchers have attributed repetition effects according to one or the other of these interpretations, a few have proposed models for repetition effects that include both abstract and instance-specific memory codes (Feustel et al., 1983; Salasoo et al., 1985).

Most proponents of the abstract memory interpretation have assumed priming of lexical but not semantic memory representations. Furthermore, only a few studies have reported evidence directly addressing the priming of abstract memory for stimulus word meaning in the repetition paradigm (Dannenbring & Briand, 1982; Ratcliff et al., 1985). These studies used lexical decision tasks and compared the magnitude and longevity of facilitation for identity and se-

mantically related repetitions. Results were consistent in showing facilitation attributable to abstract memory for meaning (i.e., the effect of semantically related repetitions) was short-lived, while facilitation from identity repetitions was more lasting.

Thus, previous evidence leads to a conclusion that priming of abstract semantic memory plays, at most, a temporary role in otherwise persistent repetition effects in verbal processing tasks. In contrast, several researchers have argued convincingly that instance memory for feature encoding underlies remarkably long-lasting effects (Jacoby, 1983; Jacoby & Hayman, 1987; Kolers, 1976; Kolers & Roediger, 1984). Kolers (1976) provided the most dramatic evidence for this argument in reporting facilitation for previously read inverted text passages after 1 year, where facilitation was not dependent on ability to discriminate new and old texts by semantic content.

Despite the evidence, these conclusions about the nature of temporary and persistent repetition effects seem suspect because they contradict evidence from other memory paradigms. That is, other research has concluded that memory for instance-specific surface features fades quickly in lieu of more abstract semantic representations for processing events. For example, in studies of stimulus comparison processes, Posner, Boies, Eichelman, and Taylor (1969) showed that facilitation for physically exact versus different case letters decayed rapidly in just a few seconds of interstimulus interval. Similarly, studies on memory for connected discourse have demonstrated that memory for surface structure decays more rapidly than memory for abstract meaning of text (e.g., Anderson, 1974; Sachs, 1967).

One reason for these apparently discrepant conclusions from repetition priming and other memory research might be the lack of semantic processing demands in previously used repetition priming tasks. Repetition priming studies have relied almost exclusively on lexical decision and word identification tasks, neither of which explicitly demands semantic processing. These tasks are complex primarily with respect to visual encoding and consequently may not adequately test the potential contribution of abstract semantic memory representations. It seems important to test competing explanations of repetition priming by using other experimental tasks, especially those involving greater semantic processing in the absence of unusual encoding demands.[1]

Repetition effects have been found in moderately complex semantic processing tasks involving word meaning comparisons (Woltz, 1988, 1989) and word category comparisons (Woltz, 1988). In a semantic comparison task involving word meanings, two words are presented on each trial (e.g., *moist damp*), and subjects decide whether their meanings are alike or different. Comparing the meaning of two words presumably utilizes semantic memory representations to a much greater extent than either lexical decision or word identification tasks. Consequently, priming of abstract semantic memory may underlie persistent repetition effects in this task, despite the lack of evidence for this in simpler tasks.

Two experiments are presented here which investigated the nature of facilitation observed in repeated semantic comparison trials. Experiment 1 investigated the role of instance memory for physical feature encoding over various repetition lags. This was done by testing for reductions in repetition effects when the typographic details of repeated trials (letter case) were altered. Although visual details have been shown to affect repetition priming in lexical decision and word identification tasks, they were hypothesized to have only a temporary effect because of increased semantic complexity in this task. Experiment 2 investigated the priming of abstract semantic memory representations as a source of repeated trial facilitation. This experiment compared facilitation from semantically related and lexically identical repetitions over various lag intervals. The presence of any facilitation for semantically related repetitions was assumed to reflect priming of abstract memory for meaning common to lexically different processing instances. The persistence of such facilitation over varied repetition lags was also tested. Previous findings from lexical decision tasks would suggest that semantically related repetitions should produce very short-lived facilitation compared with identity repetitions. However, more persistent facilitation was hypothesized because of the increased semantic complexity of this task.

Experiment 1: Instance-Specific Memory for Stimulus Orthography

Consistency of visual details has been shown to affect the magnitude of repetition effects in tasks for which subjects have had limited experience such as reading inverted text (Kolers, 1976; Masson, 1986), as well as for familiar processing tasks such as word recognition (Jacoby & Hayman, 1987). These findings have been used to argue for the importance of instance specific memory for feature encoding in repetition effects.

Previous findings from repetition priming of semantic comparison trials, however, appear contradictory to a feature-encoding explanation. Substantial latency savings were observed for trials in which one of two words and the correct response differed between prime and repeated trial (Woltz, 1989), but only when positive prime trials preceded negative target trials (e.g., *moist damp* followed by *moist blue*). Although these repetitions produced large savings (200 ms even after seven intervening trials), negative prime trials produced no savings on subsequent positive target trials (e.g., *moist blue* followed by *moist damp*).

Regardless of the memory representations involved, one expects smaller repetition effects when primes and targets have only one word in common, especially when the comparison and response processes differ. However, the asymmetric facilitation for positive–negative and negative–positive repetitions is difficult to explain in terms of memory for instance-specific encoding. Why should memory for encoding positive trial features facilitate subsequent negative trials, but

---

[1] Kolers (1976) found long-term repetition effects for reading inverted text, which is certainly semantically complex compared with lexical decision and word identification tasks. However, the most salient characteristic of the Kolers task was highly complex encoding demands. Thus, this evidence also may have biased interpretation of repetition effects toward memory for encoding processes.

not the reverse? On the other hand, this pattern conforms well to a model of spreading activation in an associative network of abstract memory codes for words and their meaning (e.g., Anderson, 1983a, 1983b). Positive prime trials should produce greater activation than negative prime trials in semantic or lexical memory nodes because only positive trial stimuli have overlapping semantic features that would share activation in the network. Thus, although previous results from repeated semantic comparisons appeared to be best explained by activation of abstract memory codes, the possible role of instance-specific memory for feature encoding in this task was uncertain.

To test the possible involvement of instance-specific encoding memory in the semantic comparison task, this experiment assessed the importance of visual details (typography) to repeated trial facilitation. Subjects performed a semantic comparison task with repeated trials similar to that used in previous studies (Woltz, 1988, 1989). Approximately one-third of all trials were repeated within 15 subsequent trials. Some repetitions used the exact stimulus set from first occurrences (thus the response stayed the same) and some repetitions were converted (one of the words from the first occurrence was replaced so that the correct response changed). Differing from previous studies with this task, half of the repeated trials of each condition preserved the case of the first occurrence, and half changed the case. Instance memory for prior feature encoding was implicated if same-case repetitions resulted in more savings than did different-case repetitions.

Method

Subjects. Subjects were 273 US Air Force recruits in their 6th day of basic training at Lackland Air Force Base, Texas. Approximately 17% of these subjects were eliminated because performance scores indicated lack of effort (i.e., chance errors rates or failure to complete the experimental tasks.) Another 3% of the subjects were eliminated because English was not their primary language. Of the remaining 219 subjects, 175 were male and 44 were female. All subjects were high school graduates, and approximately 20% had at least some college work. The age of Air Force recruits ranges from 17 to 27 years.

Apparatus. All experimental tasks were administered on Zenith Z-248 microcomputers with standard keyboards and EGA color video monitors. Materials were presented on the monitors in 24 × 80 character text mode. Software was written to achieve millisecond timing on response latency recording.

Procedure. Subjects were tested in groups of 25–35, with each subject at an individual testing carrel. Subjects were first given a brief orientation to the experimental session and practice locating keys on the keyboard. All instructions were computer administered, and proctors were available to answer questions. Total time of each session was approximately 3.5 hr. Subjects were allowed brief rests between experimental tasks and were given a 5-min break approximately halfway through the session.

Five cognitive tasks were administered to each subject during the experimental session. All subjects performed the semantic comparison task first. The remaining tasks were designed to measure individual differences in verbal knowledge and working memory capacity. Scores from these tasks were used as covariates in individual differences analyses to be presented in a later section. Only the semantic comparison task will be described here.

Repeated trial semantic comparison task. Each trial consisted of two words presented in the center of the computer display, one on top of the other separated by approximately 1 cm. Each trial was preceded by an attention cue (one asterisk) presented for 250 ms followed by a blank screen for 250 ms. The two words were then presented and remained on the screen until the subject responded by pressing either an *L* key (for Like) or a *D* key (for Different), depending on whether the subject judged the words to be synonyms or unrelated. Subjects were instructed to respond as quickly as possible without sacrificing accuracy. Response feedback was also designed to encourage attention to response speed without inducing errors. Trial response latency followed correct responses for 1,000 ms, while the word WRONG and a low tone followed errors for 1,000 ms. In addition, subjects were presented summary feedback of percent correct and median latency after each block of 75 trials and were reminded to respond as quickly as possible without sacrificing accuracy.

Each subject performed eight blocks of 75 trials. Sixteen of the 75 trials in each block were repetitions of trials presented earlier in the same block. Four orthogonal factors defined the repetitions: (a) positive versus negative match on first occurrence (e.g., *moist damp* vs. *moist blue* as the priming trial), (b) same versus different match of second occurrence relative to first occurrence (e.g., *moist blue* followed by *moist blue* is same match because both are negative matches while *moist blue* followed by *moist damp* is different match because one is negative and one is positive), (c) same versus different case of second occurrence relative to first occurrence (e.g., MOIST DAMP followed by *moist blue*, and (d) trial lag of second occurrence after first occurrence (i.e., second occurrence 1, 2, 5, or 15 trials later). A complete representation of the repeated trial design was achieved in a random order for each subject over every two 75-trial blocks.

There were 128 stimulus sets (word triplets) for repeated trials. Each stimulus set consisted of a stem word (e.g., *ample*), a synonym of the stem (e.g., *sufficient*), and a foil unrelated to the stem (e.g., *enclose*). Stimulus sets were randomly assigned to design cell and trial block for each subject.

There were 344 stimulus sets of word triplets used for nonrepeated trials. Nonrepeated trials served as fillers and were balanced within blocks for (a) positive and negative matches and for (b) upper- and lowercase presentation. The 344 stimulus sets were randomly assigned to trial type and block.

Repetition lag was accomplished in the following manner. Each block began with 7 filler trials (for warm-up) followed by four contiguous sets of 17 trials. The first trial in each set of 17 was a filler (nonrepeated trial); then the first occurrence of a Lag 15 trial was presented. The next 13 trials included the first and second occurrences of Lags 1, 2, and 5 in random order, with one filler trial separating the second occurrence of one lag from the first occurrence of the next lag. The next trial was another filler trial followed by the second occurrence of Lag 15.

Results

Performance on the semantic comparison task revealed substantial savings for both same- and different-case repetitions. For same-case repetitions, the mean of individual median response latency across trial conditions was 1,297 ms ($SD = 339$) on first-occurrence trials and 1,099 ms on second-occurrence trials ($SD = 249$). For different-case repetitions, the mean of individual median response latency across trial conditions was 1,301 ms ($SD = 353$) on first-occurrence trials and 1,125 ms on second-occurrence trials ($SD = 269$). The difference between same-case repetition savings (198 ms) and

different-case repetition savings (175 ms) was statistically significant, $F(1, 218) = 11.75$, $p < .001$.

Savings in performance accuracy were significant, $F(1, 218) = 82.99$, $p < .001$, but did not differ between same- and different-case repetitions, $F(1, 218) < 1$. For same-case repetitions, performance improved from 11.17% errors ($SD = 5.67$) on first occurrences to 8.72% errors ($SD = 5.36$) on second occurrences. For different-case repetitions, performance improved from 10.99% errors ($SD = 6.20$) on first occurrences to 8.42% errors ($SD = 4.66$) on second occurrences. There was no evidence of a speed–accuracy trade-off because the correlation between average latency and percent errors for the sample was nonsignificant, $r = -.06$, $p > .35$.

Table 1 presents mean latency savings by trial lag. Of primary interest, the savings difference between same- and different-case repetitions appeared equivalent across lags. This was confirmed by a nonsignificant Lag × Case interaction, $F(3, 216) = 1.13$, $p > .30$. Thus, as seen in Figure 1, which presents average savings collapsed over repetition type, there was a small but significant loss in savings when the case of repeated trials differed from the case of the original occurrence. However, decay of savings did not differ as a function
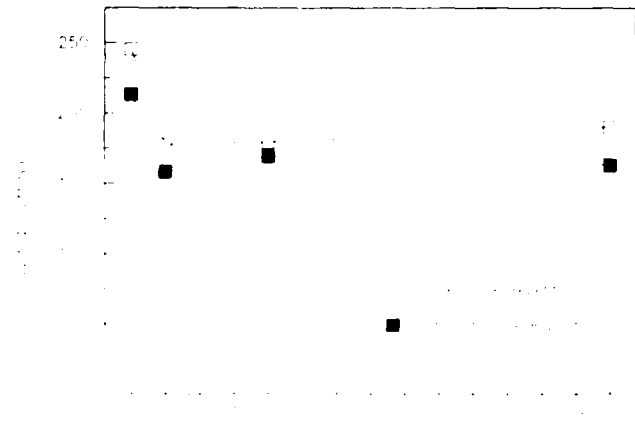
Table 1
Mean Latency Savings for Semantic Comparison Repeated Trials × Trial Condition From Experiment 1 (N = 219)

Repetition type[a]	Repetition lag (trials)				
	1	2	5	15	Combined
Same-case repetitions					
Positive–positive					
M	396	297	315	320	332
SD	242	181	195	196	158
Positive–negative					
M	194	133	123	144	149
SD	233	218	257	200	159
Negative–positive					
M	43	46	48	58	49
SD	271	215	244	236	150
Negative–negative					
M	346	232	229	237	261
SD	288	220	235	258	199
Different-case repetitions					
Positive–positive					
M	338	258	276	294	292
SD	236	244	210	212	165
Positive–negative					
M	207	130	119	125	145
SD	242	242	233	208	168
Negative–positive					
M	18	45	64	51	45
SD	256	207	255	248	147
Negative–negative					
M	289	200	218	182	222
SD	308	240	232	294	194

Note. Mean latency savings are displayed in milliseconds. Latency savings were computed as the difference between repeated trial latency and first occurrences of the same trial type within each repetition lag.
[a] The first word of each pair refers to the match type of the first occurrence, and the second word refers to the match type of the second occurrence.

Figure 1. Experiment 1: Mean latency savings for Same- and Different-Case Repetitions × Trial lag ($N = 219$).

of visual similarity; the initial savings difference between case conditions persisted through Lag 15.

Because savings scores were computed as the difference between first and second occurrences for each lag, there was more opportunity at long lags for general practice effects to contaminate savings estimates. That is, subjects could be faster at the second occurrence of Lag 15 relative to the first occurrence because of general practice effects over intervening trials. To investigate this, average change in latency was estimated across all nonrepeat trials (first occurrence and filler) within blocks. (The first seven trials of each block were warm-up trials not used in other analyses, so they were also eliminated from this analysis.) Rather than a general speed-up due to practice, there was a significant linear increase in latency over the sequence of 52 non-repeat trials in each block, $F(1, 218) = 11.31$, $p < .001$. This apparent fatigue effect was relatively small, however, at less than 0.5 ms per trial. The net result of this effect was to slightly underestimate average savings at Lag 5 by about 2 ms and savings at Lag 15 by about 7 ms. Fatigue within blocks was also reflected by a small but significant increase in errors over trials, $F(1, 218) = 5.95$, $p < .05$.

There were other differences in Table 1 of interest. First, as found earlier (Woltz, 1989), the overall effect of lag was significant, $F(3, 216) = 24.83$, $p < .001$, but the decay of savings over lag was not continuous. The presence of decay at each lag was tested by using orthogonal Helmert contrasts (Bock, 1975). These contrasts compared savings at each lag with savings from combined subsequent lags. Only the savings difference between Lag 1 and Lags 2–15 was significant, $F(1, 218) = 69.43$, $p < .001$. Both the savings difference between Lag 2 and Lags 5–15, $F(1, 218) = 1.69$, $p > .20$, and the savings difference between Lag 5 and Lag 15, $F(1, 218) < 1$, were nonsignificant. Thus, decay resulted from the first intervening trial, but not from subsequent intervening trials.

A second finding of interest in Table 1 was that savings depended on first-occurrence trial type (positive or negative), $F(2, 218) = 278.27$, $p < .001$, and on whether the second occurrence was the same trial type as the first, $F(1, 218) =$

621.75, $p < .001$. This only partially replicated the earlier finding (Woltz, 1989) described in the introduction to this experiment. In the previously study, negative-positive repetitions produced less savings than other repetition types. This difference was reflected in a significant interaction between first-occurrence trial type and consistency of first and second-occurrence trial types. In the current experiment, this interaction did not reach significance, $F(1, 218) = 2.96$, $p > .08$.

A third finding of interest in Table 1 was that case similarity interacted with trial type similarity, $F(1, 218) = 10.69$, $p < .001$. As can be seen in Table 1, case change had its greatest effect for repeated trials that were identical to their original occurrence in all other ways. That is, case change reduced savings by an average of 40 ms in positive-positive repetitions and 39 ms in negative-negative repetitions. In comparison, case change reduced savings by an average of only 4 ms in both positive-negative and negative-positive repetitions. In these latter repetitions, where only one word was retained from prime to target, the difference between same- and different-case conditions was nonsignificant, $F(1, 218) < 1$. Thus, case similarity affected savings only when all lexical components remained constant and in the same location over repetitions.

Discussion

Case changes between prime and target trials reduced the magnitude of identity priming effects in semantic comparison trials. Although the case-change effect was relatively small (10%-15% of total savings) and present only in repetitions preserving all prime trial components, it persisted over all lag intervals investigated. That is, the visual similarity of the repeated trial to its prime was as important at Lag 15 as it was at Lag 1.

The effect of case change, and particularly the persistence of this effect over trial lag, implicated instance memory for encoded features or encoding processes. The increased semantic complexity of this task over previous repetition priming tasks did not eliminate the role of instance-specific physical feature memory. Moreover, the influence of such low-level feature memory did not decay quickly as might be expected from the temporary availability of surface features in other semantic processing tasks (e.g., Anderson, 1974; Sachs, 1967).

The fact, however, that case change had no effect on positive-negative and negative-positive repetitions suggested that facilitation due to feature encoding memory may be highly context specific. Case-change effects should have been smaller on positive-negative and negative-positive repetitions because only one word in target trials matched prime trial contents. However, if the 40-ms case-change effect in positive-positive and negative-negative repetitions reflected facilitation from re-encoding two stimulus words, one would expect a 20-ms case change effect for positive-negative and negative-positive repetitions where one stimulus word was re-encoded. The absence of this effect suggests that memory for stimulus physical features or encoding processes may facilitate performance only when processing contexts are highly similar or identical.

Evidence from this study also suggested a difference between temporary and persistent identity repetition effects

similar to that described by Ratcliff et al. (1985). Noncontinuous decay of savings for both same- and different-case repeated trials suggested that some temporary memory activation for trial contents may last until one intervening trial is processed. Following the apparent loss of immediate activation, the lack of further savings decay with up to 14 intervening trials suggested additional involvement of a more persistent memory for original trial content or processing. Although repetition effects were investigated over a maximum lag of 15 trials, the complete absence of decay after Lag 1 suggested that these effects may last longer than a single experimental session. Such persistence would be consistent with findings from lexical decision and word identification experiments where single repetitions produced significant savings over several days (Jacoby, 1983; Jacoby & Dallas, 1981; Scarborough et al., 1977).

In summary, case changes resulted in persistent reductions in repetition savings under certain trial conditions, thus suggesting involvement of instance memory for encoded physical features or feature encoding processes. However, given its small magnitude, this effect did not rule out additional involvement of abstract memory for stimulus meaning.

Experiment 2: Priming of Abstract Semantic Memory

Researchers who have attributed persistent repetition effects to priming of abstract memory codes have generally assumed lexical, not semantic, representations (Dannenbring & Briand, 1982; Forbach et al., 1974; Johnston et al., 1985; Morton 1979; Scarborough et al., 1977). Furthermore, Dannenbring and Briand (1982) and Ratcliff et al., (1985) reported evidence suggesting only temporary involvement of abstract semantic memory in repetition priming. These studies used lexical decision tasks and found facilitation for semantically related repetitions to be short-lived compared with facilitation for exact repetitions. However, given the increased semantic complexity of the current task, I hypothesized that some portion of persisting repetition effects would be attributable to the priming of abstract representations of word meanings and relations.

Priming of abstract semantic representations was tested in Experiment 2 by comparing repeated trial facilitation from identity repetitions (e.g., *moist day* :p followed by *moist damp*) with facilitation from semantically similar repetitions (e.g., *moist damp* followed by *soggy wet*). The experimental apparatus and procedures were identical to those used in Experiment 1, except that half of the repeated trials were semantically related rather than identical to first-occurrence trials.

Semantically related repetitions could show less savings (or even no savings) compared with identity repetitions for two reasons. First, there can be no savings from previous physical feature encoding because there is no physical feature overlap in prime and target trials. In Experiment 1, encoding the same word pair in a different case produced a small but lasting reduction in repetition savings. Encoding entirely different words in semantic repetitions should further reduce savings due to repeated feature encoding. Second, if some part of identity repetition savings in this task is due to direct activation of abstract lexical memory representations (e.g., logo-

gens), then this portion of savings would also be eliminated by semantic repetitions.

Given the two sources of repetition savings that should be eliminated in semantically related repetitions, any observed savings were assumed to reflect priming of long-term memory structures representing the semantic content of stimulus words (e.g., concept nodes in a semantic network or links that represent semantic relations between lexical representations). This experiment addressed two questions with regard to the hypothesized priming of abstract semantic memory codes. First, are there measurable savings for semantically related repetitions? Second, if savings exist, how persistent are they? If they are as persistent as savings from identity repetitions, then priming of semantic memory codes might partially underlie persistent savings for identity repetitions. However, if savings from semantically related repetitions are relatively short-lived, as might be predicted from lexical decision data (Dannenbring & Briand, 1982; Ratcliff et al., 1985), this would suggest abstract semantic memory involvement in temporary but not persistent identity repetition effects.

Method

Subjects. Subjects were 291 Air Force recruits in their 6th day of basic training at Lackland Air Force Base, Texas. Approximately 14% of these subjects were eliminated because performance scores indicated lack of effort. Another 3% of the subjects were eliminated because English was not their primary language. Of the remaining 241 subjects, 195 were male and 46 were female.

Procedure. Subjects performed the same five cognitive tasks as in Experiment 1. Only the design of the semantic comparison task differed. Tasks other than semantic comparison will be described in a later section reporting individual differences analyses.

Repeated trial semantic comparison. This task was structured identically to the semantic comparison task in Experiment 1, except the manipulation of case similarity in repetitions was replaced with a manipulation of lexical similarity. All trials were presented in lower case. Half of all repeated trials used stimuli that were lexically identical to first occurrence trials (*identity* repetitions), and half used lexically different but semantically similar stimuli (*synonym* repetitions). That is, for each of the 128 stimulus sets used in Experiment 1 (a stem word, a semantically related alternative, and an unrelated foil), there was a synonymous stimulus set (e.g., *ample, sufficient,* and *enclose* was semantically parallel to *enough, plenty,* and *surround*). Within each design cell created by crossing lag and repetition type, half of the repeated trials used the same stimulus set, and half used the semantically parallel set. Assignment of stimulus set to trial condition and block location was random for each subject.

Results

Performance on identity repetitions resembled that from both case conditions of Experiment 1. The mean of individual median response latency for identity trials was 1,281 ms (SD = 317) on first-occurrence trials and 1,131 ms (SD = 277) on second-occurrence trials. As expected, synonym repetitions showed comparatively less savings. The mean of individual median response latency across conditions for synonym trials was 1,275 ms (SD = 303) on first-occurrence trials and 1,246 ms (SD = 302) on second-occurrence trials. The overall difference between identity repetition savings (150 ms) and synonym repetition savings (29 ms) was significant, $F(1, 240)$

= 318.07, $p < .001$. Despite the attenuation of savings for synonym repetitions, these savings were still greater than zero, $F(1, 240) = 34.54$, $p < .001$, thus suggesting the priming of abstract semantic memory codes.

Performance accuracy showed a similar pattern to that of latency. For identity repetitions, performance improved from 10.30% errors (SD = 5.68) on first-occurrences trials to 8.06% errors (SD = 4.66) on second occurrences. There were comparatively less savings in synonym repetitions; performance improved only slightly from 10.76% errors (SD = 5.12) on first occurrences to 9.53% errors (SD = 5.99) on second occurrences. As with latency savings, the accuracy savings difference was significant between identity and synonym repetitions, $F(1, 240) = 5.65$, $p < .05$, and although synonym savings were smaller, they were still greater than zero, $F(1, 240) = 15.47$, $p < .001$.

As found in Experiment 1, there was no evidence for a speed–accuracy trade-off. The sample correlation between average latency and percent errors was greater than zero, $r = .16$, $p < .05$, indicating that faster subjects made fewer errors.

Mean latency savings by trial lag are presented in Table 2. The effects of lag on savings revealed a different pattern of decay for identity and synonym repetition savings. As shown

Table 2

Mean Latency Savings for Semantic Comparison Repeated Trials × Trial Condition From Experiment 2 (N = 241)

Repetition type[a]	Repetition lag (trials)				
	1	2	5	15	Combined
Identity repetitions					
Positive–positive					
M	338	251	266	278	283
SD	215	211	202	180	131
Positive–negative					
M	152	87	87	83	102
SD	211	256	201	290	148
Negative–positive					
M	18	13	35	87	38
SD	253	230	307	180	142
Negative–negative					
M	248	165	153	137	176
SD	247	227	231	258	157
Synonym repetitions					
Positive–positive					
M	90	94	21	44	62
SD	193	222	267	263	139
Positive–negative					
M	79	28	−22	−6	20
SD	226	218	247	249	141
Negative–positive					
M	47	05	23	12	22
SD	226	256	257	213	163
Negative–negative					
M	12	47	−9	03	13
SD	220	235	258	232	142

Note. Mean latency savings are displayed in milliseconds. Latency savings were computed as the difference between repeated trial latency and first occurrences of the same trial type within each repetition lag.
[a] The first word of each pair refers to the match type of the first occurrence, and the second word refers to the match type of the second occurrence.

in Figure 2, which presents average savings collapsed over repetition type, decay for identity repetition savings resembled that of previous data: Only a portion of total savings decayed, and this occurred exclusively with one intervening trial. In contrast, savings for synonym repetitions decayed gradually but completely over the first few intervening trials. The Lag × Lexical Similarity interaction representing this difference was significant, $F(3, 238) = 6.53$, $p < .001$. Analysis of Helmert contrasts for this interaction revealed only one significant decay difference for identity and synonym repetitions which was between Lag 2 and Lags 5–15, $F(1, 240) = 18.81$, $p < .001$. Interactions of lexical similarity and Lag 1 versus Lags 2–15, $F(1, 240) = 2.07$, $p > .15$, and lexical similarity and Lag 5 versus Lag 15, $F(1, 240) < 1$, were nonsignificant.

The difference in savings decay for identity versus synonym repetitions also depended upon repetition type. The Lexical Similarity × Match Type × Lag interaction, $F(3, 238) = 8.43$, $p < .001$, was significant. Helmert contrast analyses revealed that this interaction was significant only for Lag 1 versus Lag 2–15, $F(1, 240) = 22.72$, $p < .001$. As can be seen in Table 2, there was immediate decay of initial savings for all identity repetitions, but immediate decay only for synonym repetitions that were different-match types (positive–negative and negative–positive).

As in Experiment 1, general latency change within blocks for nonrepeat trials was estimated to address possible contamination of savings by practice. Similar to results from Experiment 1, there was a significant linear increase in latency over the sequence of 52 nonrepeat trials per block, $F(1, 240) = 20.97$, $p < .001$. Again, this change reflected fatigue rather than practice. The fatigue effect amounted to approximately 0.5 ms increase per trial and thus resulted in slight underestimation of savings at longer lags. There was no change in error rate over trials of a block, $F(1, 240) < 1$.

Discussion

Results of this experiment suggested that some repetition effects are attributable to greater availability of abstract se-

mantic memory codes. Priming of abstract memory for meaning common to lexically different processing instances was inferred from significant savings in semantically related repetitions that could not be attributed to memory for recent perceptual processing or direct activation of lexical memory representations.

Also of importance was the finding that identity and semantically related repetition effects had different decay rates. As found in Experiment 1 and previous work (Woltz, 1989), identity priming effects showed an immediate but incomplete decay with one intervening trial. Following the immediate decay, savings remained constant for the 15 trial lags investigated. In contrast, facilitation from semantically related primes decayed completely over the first few intervening trials. Thus, repetition effects attributable to abstract semantic codes were short-lived while other repetition effects, including those due to physical feature encoding (Experiment 1), were more persistent. These findings are consistent with those from lexical decision experiments (Dannenbring & Briand, 1982; Ratcliff et al., 1985). So despite the increased semantic complexity of this experimental task compared with previously used tasks, similar conclusions were drawn concerning abstract and instance-specific memory codes underlying temporary and persistent repetition effects.

Although the results of this experiment implicated some form of abstract memory for meaning in temporary repetition effects, they did not make clear the specific representation or mechanism involved. Observed savings on semantically related repetitions could be attributed to spreading activation during prime trial processing to representations for or shared by probe trial contents (see Anderson, 1983b). However, recent theories of compound or composite retrieval-cue mechanisms could also explain these data (Dosher & Rosedale, 1989; Ratcliff & McKoon, 1988). That is, performance could have been faster on target repetitions that were semantically related to previous prime trials because memory representations for prime and target trial contents formed a compound cue during target trial processing. Despite the different mechanisms assumed by spreading activation and compound-cue theories, both assume involvement of existing semantic memory structures such as semantic concept nodes or associative links between lexical representations.

Experiments 1 and 2: Individual Differences

Individual differences were analyzed as an alternative test of the hypothesized role of abstract semantic memory representations in repetition priming. If repetition effects are attributable to increased availability of existing semantic memory structures for stimulus words, then individual differences in the magnitude of priming effects should be related to differences in verbal knowledge (e.g., as indicated by performance on a vocabulary test). That is, differences in vocabulary test performance should reflect differences in the quantity and organization of memory representations for word meanings and relations. These differences should be positively related to the magnitude of repetition savings if savings reflect either temporary or persistent changes (e.g., activation or strengthening) to these memory structures. However, if se-
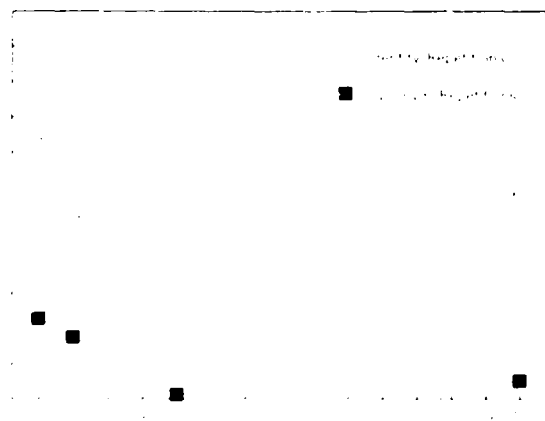

Figure 2. Experiment 2: Mean latency savings for Identity and Synonym Repetitions × Trial Lag ($N = 241$).

mantic memory structures are involved only temporarily when prime trials are semantically related but not identical to targets (as predicted from Ratcliff et al., 1985), then individual differences in verbal knowledge should be related only to repetition effect differences in the synonym repetition condition in Experiment 2.

Any pattern of correlations between verbal knowledge and savings for different repetition conditions would be difficult to interpret unless measures of other cognitive constructs showed divergent patterns. Tasks designed to measure individual differences in working memory capacity were included for this purpose. Earlier work found that working memory differences were largely unrelated to the magnitude of identity priming effects (Woltz, 1989). However, possible relations between working memory measures and semantic priming effects were not tested.

In both Experiments 1 and 2, subjects performed a verbal knowledge and two working memory tasks in addition to the repeated-trial semantic-comparison task. The verbal knowledge measure was a traditional multiple-choice vocabulary test. Working memory tasks were designed to measure performance errors under concurrent demands for processing (verbal or numeric) and temporary information storage. This operationalization of working memory capacity is consistent with the model proposed by Baddeley (1986). Analyses reported here evaluated relations between these measures and savings from both identity and semantic repetitions. Supplemental analyses of verbal knowledge and working memory task performance are presented in the Appendix.

Method

Subjects, apparatus, and procedures were those previously described for Experiments 1 and 2. Subjects performed the verbal knowledge and working memory tasks in a random order following the semantic comparison task. Detailed descriptions of the verbal knowledge and working memory tasks are presented in the Appendix.

Results

Analyses of individual differences in repeated trial savings relied on regression residual rather than difference score measures of change (for discussions see Cronbach & Snow, 1977; Donaldson, 1983). That is, subjects' median latencies for repeated trials were regressed on median latencies for first-occurrence trials, and residuals were taken to reflect relative savings (large savings were represented by negative residuals: subjects who were faster on repeated trials than predicted by their first-occurrence latency). Residual savings scores approximated a normal distribution for both experiments, except for a few extreme values. To reduce the influence of these extreme values on correlations, residual savings greater than three standard deviations from the mean were replaced with that value (23 subjects across both experiments).

First, reliability estimates and intercorrelations were computed for savings measures within each experiment. For Experiment 1, split-half reliability estimates were $r = .66$ for same-case savings and $r = .72$ for different-case savings. The correlation between these two savings scores was $r = .65$,

$p < .001$. Thus, the magnitude of savings for same- and different-case repetitions was correlated almost to the limit imposed by measurement reliability (a correlation of $r = .69$ would be the maximum expected correlation, given estimated reliabilities). Such a high relation suggested that the same processes and memory structures were responsible for repetition savings in these two conditions.

For Experiment 2, split-half internal consistency reliability estimates were $r_{ii} = .60$ for identity repetition savings and $r_{ii} = .69$ for synonym repetition savings. The correlation between these savings scores was $r = .51$, $p < .001$. This correlation was significantly lower than the correlation between conditions in Experiment 1, $z = 2.26$, $p < .05$,[2] despite comparable reliabilities. This suggested that, in contrast to Experiment 1, partially different processes or memory codes may have been involved in the repetition effects for the identity and synonym repetition conditions of Experiment 2.

Next, correlations of repetition savings with verbal knowledge and working memory were estimated. Table 3 presents these correlations for Experiment 1. As expected from the high correlation between repetition conditions of Experiment 1, correlations in Table 3 did not differ significantly across conditions for either verbal knowledge or working memory measures ($p > .10$).[3] This again suggested that manipulating visual similarity of repetitions did not substantially change processes underlying the repetition effects.

Also of interest in Table 3 was that verbal knowledge, as measured by the vocabulary test, appeared to have lower correlations with savings than did working memory. Verbal knowledge correlations with savings were significantly lower than verbal working memory correlations with savings for both same-case, $t(216) = 2.02$, $p < .05$, and different-case conditions, $t(216) = 2.45$, $p < .01$. Differences between the verbal knowledge and numeric working memory correlations with savings approached but did not reach significance ($p < .08$).

Table 4 presents Experiment 2 correlations of repetition savings with verbal knowledge and working memory measures. As seen in Table 4, correlation patterns were similar to those for Experiment 1 (Table 3) with one exception. As in Experiment 1, correlations of the working memory tasks with savings did not differ across conditions ($p > .25$). However, in contrast to Experiment 1, the verbal knowledge measure had a significantly higher correlation with synonym savings ($r = .36$) than with identity savings ($r = .19$), $t(238) = 2.84$, $p < .005$. Furthermore, when corresponding correlations for Experiment 1 and Experiment 2 were compared, only the vocabulary-different-case savings correlation from Experiment 1 ($r = .14$) and the vocabulary-synonym savings correlation from Experiment 2 ($r = .36$) differed significantly, $z = 2.51$, $p < .01$. Thus, verbal knowledge was uniquely related to the magnitude of savings in the synonym repetition condition of Experiment 2.

[2] Difference between correlations from independent samples were tested with Fisher's transformation to z (Guilford & Fruchter, 1973).

[3] Differences between correlations from one sample involving a common variable were tested with Hotelling's t test (Guilford & Fruchter, 1973).

Table 3

Experiment 1 Correlation of Semantic Comparison Repeated Trial Savings Residual With Verbal Knowledge and Working Memory (WM) Measures by Repetition Type (N = 219)

Predictor	Repetition type	
	Same case	Different case
Vocabulary test errors	.11	.14
Verbal WM task errors	.27	.33
Numeric WM task errors	.24	.27

Note. A negative semantic comparison residual represented greater savings: someone faster on repeated trials than predicted from original trial times. Correlations greater than $r = .18$ were significantly different from zero at $p < .01$.

Discussion

Of primary interest in these analyses was that individual differences in verbal knowledge correlated significantly higher with semantically related repetition savings than with lexically exact repetition savings. In contrast, working memory measures had equivalent correlations with all repetition savings. This suggested that abstract semantic memory structures may underlie only temporary repetition effects when prime and target are semantically related. If abstract semantic representations are also involved in identity priming, they probably affect only temporary and not persistent repetition effects.

Correlations reported here also addressed an issue pertaining to two seemingly distinct conceptualizations of working memory capacity found in the literature. In Anderson's (1983a) ACT* theory, working memory was defined as currently active long-term memory nodes. Working memory capacity was defined in large part by limits of automatic spreading activation and decay in existing memory structures. In contrast, Baddeley (1986) defined working memory as a limited-capacity workspace for temporary storage and processing of information. Working memory capacity was defined by Baddeley in terms of limits within specialized temporary storage structures and of a central executive that coordinates and controls processing and storage operations. Capacity limits of Baddeley's working memory components were associ-

Table 4

Experiment 2 Correlation of Semantic Comparison Repeated Trial Savings Residual With Verbal Knowledge and Working Memory (WM) Measures by Repetition Type (N = 241)

Predictor	Repetition type	
	Identity	Synonym
Vocabulary test errors	.19	.36
Verbal WM task errors	.23	.27
Numeric WM task errors	.32	.32

Note. A negative semantic comparison residual represented greater savings: someone faster on repeated trials than predicted from original trial times. Correlations greater than $r = .18$ were significantly different from zero at $p < .01$.

ated more with controlled attention processes than with automatic activation as in Anderson's model.

Previous research showed negligible relations between measures of working memory corresponding to Baddeley's definition and repetition priming effects thought to reflect automatic memory activation processes (Woltz, 1988, 1989). These studies concluded that the two conceptualizations of working memory represent separate processing capacity limits. However, the previous studies measured savings only from identity repetitions. Semantically primed repetitions may better represent capacity-limited temporary activation processes, given that spreading activation may be involved.

Correlations from Experiment 2 tested relations between measures representing Baddeley's working memory construct and both semantic and identity priming effects. All priming effects had modest correlations (.23 to .32) with working memory tasks, and correlations did not differ between semantic and identity priming conditions. Even when unreliability of measurement was taken into consideration, shared variance between working memory and repetition savings was less than 20% in all cases. Thus, as concluded in previous studies (Woltz, 1988, 1989), activation and attention processes that are central to popular working memory models seem to represent largely independent cognitive processing limits.

General Discussion

The primary question addressed by these experiments was whether previous conclusions about memory representations underlying repetition effects in verbal tasks were valid when semantic processing demands were increased. Previous research, primarily using lexical decision and word identification tasks, suggested that abstract semantic memory plays at most a temporary role, while instance memory for encoded features or encoding processes underlies highly persistent repetition effects.

Two converging sources of evidence in the current studies suggested conclusions similar to those from previous studies using simpler processing tasks. First, repetition effects directly attributable to abstract semantic memory were short-lived, while other repetition effects, including those directly attributable to memory for physical feature encoding, persisted throughout the lags investigated with no sign of decay. Second, individual differences in verbal knowledge correlated almost exclusively with magnitude of short-lived semantic repetition effects, while individual differences in working memory correlated uniformly with all repetition effects. These findings in conjunction with those from previous research suggest that temporary and persistent components of repetition priming, and their probable underlying memory representations, are consistent across cognitive tasks that differ considerably in semantic complexity.

As stated in the introduction to this article, repetition priming effects may have direct relevance to theories of knowledge and skill acquisition. Findings from several previous studies support this view. Salasoo et al. (1985) demonstrated that simple repetition effects in pseudoword identification led to long-lasting lexical memory representations that appeared similar to those for words acquired through normal language

use. In research on skill acquisition, Masson (1986) demonstrated that skill in identifying typographically transformed words was dependent on repetition effects for specific letter forms and combinations. Moreover, Kolers (1976) showed that skill at reading inverted text, presumably built from simple repetition effects, given the findings of Masson (1986), persisted for at least a year without intermittent repetitions. In combination, these studies suggest the possibility that seemingly simple facilitation effects from repeated processing events may be the building blocks for the acquisition of complex and long-lasting skills.

Research on individual differences in skill acquisition has provided additional evidence regarding the role of simple repetition effects in more complex skill acquisition. Woltz (1988) and Chaiken (1989) found that individual differences in repetition priming effects from the semantic comparison task predicted late but not early stages of skill acquisition. These relations were interpreted in terms of a production system model of skill acquisition. That is, extended practice of initial production sequences was assumed to result in *composition*, or direct associations between appropriate terminal actions and all necessary conditions in the production sequence. Production composition was hypothesized to rely on the same memory mechanisms underlying simple repetitions effects. The correlations between repetition priming effects and performance during later stages of skill practice, when composition was assumed to occur, supported this hypothesis.

Although the relations between repetition effects and skill acquisition reported by Woltz (1988) and Chaiken (1989) were interpreted with respect to a production system model of skill acquisition, the work of Masson (1986) suggests that repetition effects may also correspond to memory mechanisms assumed by instance theories of skill acquisition. Instance theories assume that each processing episode during skill practice results in a separate memory representation and that skill acquisition depends on growing data base of such instances in memory (Logan, 1988). Obviously, a persistent memory effect from single processing episodes is central to such a theory.

The data presented here, in addition to previous findings, provide some evidence regarding memory representations underlying repetition effects. It appears that regardless of a task's semantic complexity, persisting repetition effects are more readily attributable to instance-based memory for previous encoding than to strength changes in abstract memory representations. However, given the relevance of repetition priming to fundamental mechanisms assumed by both production system models and instance theories of skill acquisition, a far more detailed understanding of this phenomenon should be the goal of future research.

References

Anderson, J. R. (1974). Verbatim and propositional representation of sentences in immediate and long-term memory. *Journal of Verbal Learning and Verbal Behavior, 13*, 149-162.

Anderson, J. R. (1983a). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Anderson, J. R. (1983b). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior, 22*, 261-295.

Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon Press.

Bertelson, P. (1961). Sequential redundancy and speed in a serial two-choice responding task. *Quarterly Journal of Experimental Psychology, 12*, 90-102.

Bertelson, P. (1963). S-R relationships and reaction times to new versus repeated signals in a serial task. *Journal of Experimental Psychology, 65*, 478-484.

Bertelson, P., & Renkin, A. (1966). Reaction times to new versus repeated signals in a serial task as a function of response-signal time interval. *Acta Psychologica, 25*, 132-136.

Bock, R. C. (1975). *Multivariate statistical methods in behavioral research*. New York: McGraw-Hill.

Chaiken, S. R. (1989). *Activation capacity, activation decay, and memory strength: Three predictors of skilled performance*. Manuscript submitted for publication.

Cronbach, L. J., & Snow, R. E. (1977). *Aptitudes and instructional methods*. New York: Irvington.

Dannenbring, G. L., & Briand, K. (1982). Semantic priming and the word repetition effect in a lexical decision task. *Canadian Journal of Psychology, 36*, 435-444.

Donaldson, G. (1983). Confirmatory factor analysis models of information processing stages: An alternative to difference scores. *Psychological Bulletin, 94*, 143-151.

Dosher, B. A., & Rosedale, G. (1989). Integrated retrieval cues as a mechanism for priming in retrieval from memory. *Journal of Experimental Psychology: General, 118*, 191-211.

Feustel, T. C., Shiffrin, R. M., & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General, 112*, 309-346.

Forbach, G. B., Stanners, R. F., & Hochhaus, L. (1974). Repetition and practice effects in a lexical decision task. *Memory & Cognition, 2*, 337-339.

Guilford, J. P., & Fruchter, B. (1973). *Fundamental statistics in psychology and education*. New York: McGraw-Hill.

Hintzman, D. L. (1969). Recognition time: Effects of recency, frequency, and the spacing of repetitions. *Journal of Experimental Psychology, 79*, 192-194.

Jacoby, L. L. (1983). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 21-38.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110*, 306-340.

Jacoby, L. L., & Hayman, C. A. G. (1987). Specific visual transfer in word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 456-463.

Johnston, J. C., van Santen, J. P. H., & Hale, B. L. (1985). Repetition effects in word and pseudoword identification: Comment on Salasoo, Shiffrin, and Feustel. *Journal of Experimental Psychology: General, 114*, 498-508.

Kolers, P. A. (1976). Reading a year later. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 554-565.

Kolers, P. A., & Roediger, H. L., III (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior, 23*, 425-449.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95*, 492-527.

Masson, M. E. J. (1986). Identification of typographically transformed words: Instance-based skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*, 479-488.

Morton, J. (1979). Facilitation in word recognition: Experiments causing change in logogen model. In P. A. Kolers, M. E. Wrolstad, & H. Bouma (Eds.), *Processing of visible language* (pp. 259-268). New York: Plenum Press.

1402   DAN J. WOLTZ

Posner, M. I., Boies, S., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. *Journal of Experimental Psychology, 79*(1, Pt. 2).

Ratcliff, R., Hockley, W., & McKoon, G. (1985). Components of activation: Repetition priming effects in lexical decisions and recognition. *Journal of Experimental Psychology: General, 114,* 435–450.

Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review, 95,* 385–408.

Sachs, J. D. S. (1967). Recognition memory for syntactic and semantic aspects of connected discourse. *Perception & Psychophysics, 2,* 437–442.

Salasoo, A., Shiffrin, R. M., & Feustel, T. C. (1985). Building permanent memory codes: Codification and repetition effects in word identification. *Journal of Experimental Psychology: General, 114,* 50–77.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 1–17.

Woltz, D. J. (1988). An investigation of the role of working memory in procedural skill acquisition. *Journal of Experimental Psychology: General, 117,* 319–331.

Woltz, D. J. (1989). *Two constructs of working memory capacity: Attention and activation.* Manuscript submitted for publication.

Appendix

Individual Difference Measures

Verbal Knowledge and Working Memory Task Descriptions

Vocabulary test. This task consisted of 32 multiple-choice vocabulary items similar to those found in conventional pencil-and-paper vocabulary tests. Items consisted of a target word and five words as response alternatives numbered 1 to 5. Subjects were instructed to find the response alternative that was most similar to the target word in meaning. Subjects responded by pressing the number key corresponding to their choice.

All subjects received the same items in a fixed order. Accuracy feedback was provided for 1,000 ms after each response. Instructions to the test emphasized the importance of accuracy, not speed.

Verbal working memory. This task required subjects to maintain a memory load of words in sequence and concurrently respond to probes concerning the order and meaning of the words. On each of 18 trials, subjects were presented with a set of three, four, or five semantically unrelated one-syllable words to remember in sequence (e.g., *wood, rich, poke, job*). Following a 1,000-ms *get ready* attention cue, stimulus words were presented one at a time at a rate of 1,000 ms per word. Then, three multiple choice probes were presented sequentially. Each probe presented a word from the set with a number ranging from −2 to +2 (e.g., *poke* −1), along with five response alternatives (e.g., *occupation, jab, pony, lumber, wealthy*). Subjects were to interpret the word–number statement to find another word, either forward or backward in the list from the designated word, and select its synonym from the five alternatives (*wealthy* for the example given).

Probes were constructed in such a way that words from different locations in the list were probed with equal frequency. In addition, probe order was balanced with original list location.

There were 23 five-word fixed order stimulus sets created for this task. Eighteen stimulus sets were randomly selected for each subject and randomly divided among the three memory set sizes.

For trials representing a memory set of five, all five words were presented in the fixed list order. For four-word memory set trials, a random choice was made to present Words 1–4 or Words 2–5 from the fixed list order. For three-word memory set trials, a random choice was made to present Words 1–3, 2–4, or 3–5 in order.

There were five multiple choice alternatives for each probe. These represented the entire set of synonyms from the stimulus set for that probe. For each probe of a list, the order of the five alternatives was randomized.

Feedback was presented after all three probes for a list were answered. Accuracy feedback (number correct out of three) was presented for 2,000 ms. This was followed by a 2,000-ms intertrial time before the next *get ready* cue. There was a 15-s time limit imposed on all probe frames. If time was exceeded, there was a message "Too much time," and the subject was moved to the next probe.

Numeric working memory. This task required subjects to perform simple arithmetic computations and to remember the solutions for expressions presented in five locations from left to right across the computer screen. On some trials more than one expression was presented per position in which case the most recent expression was to be remembered. The number of expressions presented per trial varied from 1 (only the leftmost position) to 10 (two expressions per position, presenting the first five left to right and then the second five left to right).

Only one position was probed for recall per trial, and each location was probed an equal number of times across trials. Each position was probed once with 0, 1, 2, 3, and 4 subsequent expressions following its presentation. Varying the number of subsequent expressions involved different numbers of value replacements for different probe positions. So, although probe position was crossed with number of subsequent memory inputs, a confound existed between position, number of subsequent inputs, and the number of position value replacements required.

The trials described above constitute a 5 × 5 (Probe Position × Number of Subsequent Memory Inputs) factorial task design with the noted confound. Five additional trial types were added in an attempt to control for subjects' attentiveness to position values that were replaced. Because trials representing the 5 × 5 design never probed positions that had been replaced, subjects were potentially led to ignore them. The five trial types added to the design probed each position once after all five positions had been presented and replaced.

Each subject was presented initial instructions and eight practice items. Following the initial instructions, four sets of the 30 trials were presented. Half of the trials were presented at a rate of 750 ms per stimulus position, and half at 1,500 ms per stimulus position. The order of trials was randomized for each subject.

The numeric expressions used only single digits and addition or subtraction operators, and they all evaluated to single-digit solutions. Also, expressions were generated in such a way that there were unique values at each position, and replacement values for a position could not equal the original value. Expressions meeting these constraints were randomly generated for each subject.

After all arithmetic expressions for a given trial had been presented, a probe frame appeared with blanks at each of the five positions and a question mark in one position. Subjects responded by pressing a number key from the top row of the keyboard. Accuracy feedback was provided after each response for 500 ms. Between trials there was a 1,000-ms delay of blank screen and a *get ready* warning for 2,000 ms.

Verbal Knowledge and Working Memory Results

The vocabulary test had a mean percent error of 40.52 (SD = 18.79). A subset of the sample had previously taken the Armed Services Vocational Aptitude Battery (ASVAB), which also contained a vocabulary subtest. The correlation of the current vocabulary test with ASVAB vocabulary was r = .77 (N = 330). Thus, the vocabulary task appeared to adequately reflect differences in verbal knowledge as measured by a standard paper-and-pencil vocabulary test.

The verbal working memory task had a mean percent error across all trial facets of 28.95 (SD = 15.65). Performance errors by trial facet are presented in Table A1. As seen in Table A1, there was a substantial effect of list length on performance errors, $F(2, 458)$ = 705.45, p < .001, and a smaller effect of probe order, $F(2, 458)$ = 47.13, p < .001. There was also a small, but reliable List Length × Probe Order interaction, $F(4, 456)$ = 3.38, p < .01, with only the interaction of linear components reaching significance in univariate tests, $F(1, 459)$ = 6.97, p < .01. Thus, performance on the verbal working memory task was consistent with Baddeley's (1986) model of working memory which predicts more processing errors with concurrent memory and processing demands.

The mean percent error for the numeric working memory task was 34.05 (SD = 15.73). Performance errors by trial facet are presented in Table A2. As evident in Table A2, performance errors were a function of presentation rate, $F(1, 459)$ = 538.57, p < .001, prior memory load (linear and quadratic components), $F(2, 458)$ = 1,015.72, p < .001, and subsequent processing and memory load (linear and quadratic components), $F(2, 458)$ = 858.15, p < .001. In addition, interactions were significant between rate and prior memory load, $F(2, 458)$ = 46.41, p < .001, rate and subsequent memory load, $F(2, 458)$ = 12.62, p < .001, and prior and subsequent memory loads, $F(4, 456)$ = 163.19, p < .001. Thus, this task also conformed to Baddeley's conceptualization of working memory in that errors were partly a function of concurrent processing and storage demands.

Correlations among verbal knowledge and working memory tasks are presented in Table A3. Split-half internal consistency reliability estimates are presented on the diagonal. As expected, the working memory measures correlated with one another to a greater extent than they did with verbal knowledge. Also as expected, the verbal working memory task correlated higher with the verbal knowledge measure than did the numeric working memory task.

Table A1
Verbal Working Memory Mean Percent Errors by Trial Type for Experiment 1 and 2 Combined (N = 460)

List length (LL)	Probe order		
	1	2	3
LL 3			
M	13.30	16.16	16.20
SD	18.41	18.98	20.06
LL 4			
M	20.94	27.28	27.57
SD	20.52	23.11	23.85
LL 5			
M	42.36	47.79	48.99
SD	24.87	23.68	23.98

Table A2
Numeric Working Memory Mean Percent Errors × Trial Type for Experiment 1 and 2 Combined (N = 460)

Prior memory load (PML)	Subsequent memory & processing load				
	0	1	2	3	4
Fast trials					
PML 0					
M	7.17	11.41	15.76	20.33	25.65
SD	18.16	24.14	27.94	30.52	34.21
PML 1					
M	11.52	20.33	28.37	34.13	39.67
SD	24.21	32.08	36.22	37.32	37.73
PML 2					
M	15.11	30.43	40.33	47.50	60.11
SD	27.12	34.90	38.62	37.33	37.50
PML 3					
M	19.78	37.93	53.48	59.89	68.59
SD	29.70	37.36	38.90	36.08	33.94
PML 4					
M	23.15	48.91	55.54	59.46	62.39
SD	31.52	38.19	39.15	37.82	38.89
Slow trials					
PML 0					
M	5.98	7.61	10.43	12.17	17.07
SD	18.14	20.53	23.57	25.71	30.02
PML 1					
M	6.20	12.61	15.43	20.98	30.43
SD	17.45	25.86	27.83	32.00	35.51
PML 2					
M	5.98	18.15	24.67	34.57	47.07
SD	17.53	29.37	33.41	36.76	37.30
PML 3					
M	8.91	24.35	39.78	46.96	55.43
SD	21.05	34.05	36.21	38.51	38.10
PML 4					
M	7.50	26.63	38.80	41.74	50.54
SD	20.16	33.86	36.60	39.01	39.81

In summary, tasks designed to measure individual differences in verbal knowledge and working memory appeared to be satisfactory for this purpose. Errors on both working memory measures corresponded to general predictions made by Baddeley's (1986) working memory model. All performance scores showed sufficient and comparable internal consistency reliability, and correlations among tasks conformed to convergent and discriminant construct validity predictions.

Table A3
Correlations Among Verbal Knowledge and Working Memory Measures (WM) for Experiments 1 and 2 Combined (N = 460)

Variable	1	2	3
1. Vocabulary % errors	.87[a]	.29	.09
2. Verbal WM % errors		.89[a]	.44
3. Numeric WM % errors			.90[a]

Note. Correlations greater than r = .13 were significantly different from zero at p < .01.
[a] Split-half reliability estimate.